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Centrality Dependent Strange Baryon Production in p-A and its Implications for Heavy Ion Collisions

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Centrality dependent strange baryon production in p-A and its implications for heavy ion collisions

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Abstract. BNL E910 has measured strange baryon production as a function of collision centrality for 17.5 GeV/c p-Au collisions. Collision centrality is defined by ν, the mean number projectile-nucleon interactions estimated from the "grey" track multiplicity. The measured Λ yield increases faster than the participant scaling expectation for $\nu \leq 3$ and then saturates. A simple parameterization of this dependence applied to nucleus-nucleus collisions reproduces the measured E866 kaon and WA97 Λ centrality dependent yields. The increase in Λ production to $\nu \leq 3$ is also evident for Λs which are leading baryons, in disagreement with predictions from RQMD.

1. Introduction

High-energy interactions of hadrons in nuclear matter have challenged experiments and theorists for more than fifty years. Initial insights into the physics of hadron-nucleus collisions from cosmic ray emulsions were confirmed by a series of FNAL experiments conducted twenty-five years ago [1, 2]. The phenomenological description of hadron-nucleus collisions which subsequently emerged has survived until the present, without modification. In this description [3], "The incident hadron interacts with a number of target nucleons (ν), derived from the collision geometry and the inelastic hadron-nucleon cross-section, and evolves into a multiparticle final state which depends on ν." Total charged particle multiplicities in proton-nucleus collisions relative to proton-proton collisions were observed to obey a wounded nucleon or participant scaling given by Eq. 1, where the number of participants in p-A collisions is given by $(1+\nu)$.

$$N_{\rm pA}/N_{\rm pp} = \frac{1}{2}(1+\nu), \tag{1}$$

The scaling of experimental signatures in heavy-ion collisions with the number of participant nucleons are nearly all based upon this physical description of p-A collisions. Yet, the validity of participant scaling of strange particle production has never been rigorously demonstrated. Heavy ion data on strange particle production from both the AGS [4] and CERN [5] show clear deviations from the simple participant scaling that is implied by Eq. 1. To understand the significance of these deviations it is necessary to extend the current body of data from p-A to include participant scaling of strange particles. Recent experiments at the BNL AGS (E910, E941) and CERN SPS (NA49) provide the first opportunity in twenty-five years to revise old models of particle production in p-A collisions. In particular BNL E910 can measure strange particle production (Λ, Ξ^-, $K^{+/-}$, K_s, ϕ) over a large range of ν per target as determined from the "grey" track multiplicity. Here we present a systematic study of Λ production vs. ν, and discuss its implications for A-A strange baryon production and its relevance to the phenomenological description of p-A collisions presented above.

2. Data Reduction

BNL E910 is a large acceptance TPC spectrometer experiment with downstream drift chambers, Čerenkov detector, and time-of-flight wall. The experimental layout and details are given in [6]. The experiment ran in 1996 in the MPS (A1) secondary beam line at the BNL AGS. Protons with beam momenta of 6.5, 12.3, and 17.5 GeV/c were normally incident on targets of Be, Cu, Au, and U. A total of 20 M central and minimum bias events were collected over all targets and beam momentum. Only the 17.5 GeV/c p-Au data are included in this analysis, for a total of 4.5 M triggers and 150 K Λs after all cuts. Details of the tracking and dE/dx particle identification are found in [6, 7, 8].

The determination of ν from N_{grey} is an important element of the scaling analysis. Our analysis is similar to earlier models [9, 10]. We assume a glauber distribution for $P(\nu)$, here obtained from Hijing [11], and assume that the mean number of grey tracks measured in the TPC can be expressed as a second order polynomial in ν. The coefficients of the polynomial are determined from a fit to the minimum bias distribution for N_{grey}, where N_{grey} is defined as the number of protons with momentum between 0.025 and 1.2 GeV/c plus the number of deuterons in the range 0.05 and 2.4 GeV/c. Details of this analysis are given in [6]. With different cuts and

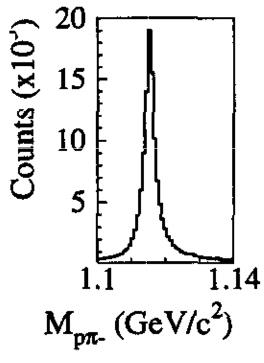

Figure 1. Invariant mass distribution for proton-pion pairs with vertex cuts.

comparisons to RQMD we determined the relative systematic errors for $\nu(N_{grey})$ to be 15%. Observations of increasing pion multiplicity up to $\nu = 8$ confirm the ability to measure large ν with the TPC [12].

For the Λ analysis positive/negative tracks are identified as protons/pions if they have a TPC dE/dx value within 2.5σ of parameterized Bethe-Bloch curves. The secondary decay vertices are included in a refit of the daughter momenta. We require $\chi^2/dof < 10$ and the decay vertex to be 3.5 cm downstream from the primary (target) vertex. Additional kinematic cuts are applied to the number of TPC hits, the proton decay angle, and the alignment of the λ momentum with the primary vertex, and minimum transverse relative momentum [7, 8]. The invariant mass distribution in Fig. 1 has a Gaussian width of 1.3 MeV. The background levels were obtained by binning in y-p_T cells of 0.2 by 0.2 GeV/c and fitting the combined signal and background in the range of 1.090 to 1.141 GeV to a double Gaussian. A Monte Carlo sample of 20 M Λs were thrown in GEANT and reconstructed to correct for experimental acceptance and momentum resolution smearing.

3. Results

The corrected m_T spectra are shown in Fig. 2 for different bins in rapidity and $N_{grey} = 0$. The open squares are bins in which the background could not be accurately determined and for which no subtraction was performed. The solid lines are fits of exponentials in m_T to the background subtracted data points. This functional form provided the best fits to the data, although Boltzmann distributions also worked well. This figure also shows the integrated rapidity distributions for each N_{grey}. The lines are gamma function fits to the distributions. These fits were used to obtain the total Λ yield as a function of $\nu(N_{grey})$.

The Λ yield vs. ν is plotted in Fig. 3. The open symbols are the integrated gamma function yields, and the errors shown represent 90% confidence limits including systematic effects from the extrapolations. The filled symbols are the fiducial yields. The various lines represent different functional scalings. The solid line is the wounded scaling of Eq. 1. The dot-dashed line is a straightforward scaling by the number of collisions, $N_{pp} \cdot nu$. N_{pp} is the measured Λ production from p-p collisions, interpolated to an energy of 17.5 GeV/c [13]. The dashed line is a parameterized fit to the data

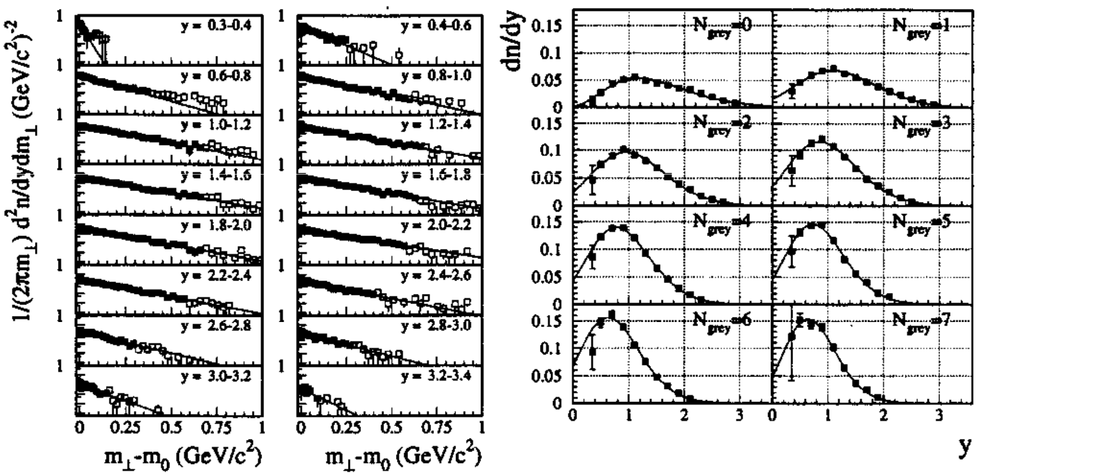

Figure 2. Transverse mass for $N_{grey} = 0$ and rapidity spectra for several values of N_{grey}.

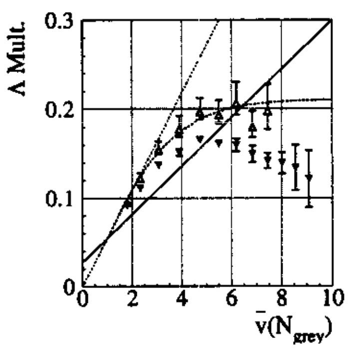

Figure 3. Λ yield for 17.5 GeV/c p-Au vs. $\nu(N_{grey})$. Open symbols are acceptance corrected. See text for details.

given by Eq. 2 with $\kappa = 0.299 \pm 0.008$ and $\alpha = 1.29 \pm 0.03$.

$$N_{pp} \cdot (1 - e^{-\kappa\nu^{\alpha}})/(1 - e^{-\kappa}) \qquad (2)$$

The deviation in strange particle production from a wounded nucleon scaling that was previously observed only in heavy-ion collisions is readily apparent in Fig. 3 for p-A collisions. The yield rises more quickly than the wounded nucleon scaling for $\nu \leq 3$ and then saturates. Although the wounded nucleon model is too simple to be expected to encompass all of the complex processes in a p-A collision, comparisons to it may still yield some insights. Using baryon conservation and the fact that $\Lambda - \overline{\Lambda}$ production is negligible at these energies, we conclude that either successive collisions of the projectile continue to contribute to Λ production, or that nucleons not directly struck by the projectile contribute. To investigate the first hypothesis, we identify those Λs which are the leading baryon in an event, and assume that for small ν, these

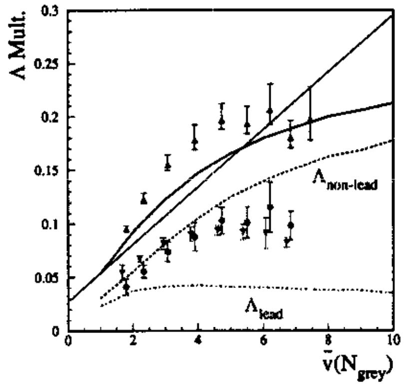

Figure 4. Λ yield vs. $\nu(N_{grey})$ for events in which the Λs are (inverted triangles) and aren't (circles) the leading baryon in the event.

can be associated with the projectile.

Fig. 4 shows yields separated into leading and non-leading components, as well as comparisons to RQMD. The solid circles are the non-leading Λs vs. ν. Both leading and non-leading components are observed to rise for small $\nu \leq 3$. For larger values of ν the distinction becomes meaningless at this beam energy. The straight line is the wounded-nucleon scaling. The solid curve is the Λ yield from RQMD. The dashed/dot-dashed lines are the non-leading/leading components. We note that in this range, RQMD underpredicts the total Λ yield, and this difference appears to come mainly from the leading Λ contribution.

4. Discussion

To estimate the implications of our results for strangeness in heavy-ion collisions, we parameterize the fast rise and saturation of the total Λ yield vs. ν according to Eq. 3.

$$N_{\Lambda/K} = \begin{array}{l} N_{pp} \cdot \nu/2; \nu \leq 3 \\ N_{pp} \cdot 3/2; \nu > 3 \end{array} \qquad (3)$$

We assume that at AGS energies Kaons are produced predominantly in association with Λs, and therefore can also be parameterized in this way. We furthermore assume that at both the AGS and CERN, the energy dependence enters into the yields only in the initial coefficient which represents the measured production from proton-proton interactions. Fig. 5 shows the measured yields for K^+ by E866 [4] and the relative yields (relative to p-Pb) for Λ by WA97 [5]. The thin solid lines show the traditional wounded nucleon scaling. The thicker solid lines are the extrapolations from E910 using Eq. 3, summed over each nucleon in the projectile/target, with ν for each nucleon taken from a glauber model. These simple extrapolations yield a close approximation to the measured data points that is far superior to the traditional wounded nucleon scaling, and for non-central data from E866 significantly better than RQMD. We note that this extrapolation from p-A is not intended to fully reproduce the nucleus-nucleus data, but rather to serve as a calibration in place of the wounded-nucleon scaling. Deviations from the extrapolation can then be understood to be from processes which are only present in A-A collisions. For example the sharp rise in kaon production for the most central E866 data may be due to the effects of rescattering.

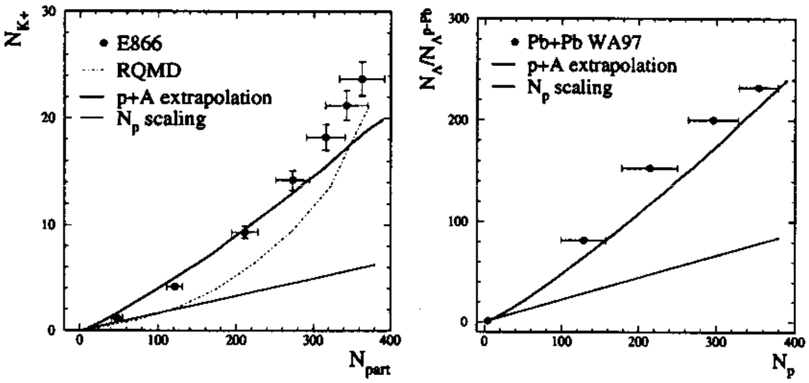

Figure 5. Λ yields from E866 and Wa97 and extrapolations from the E910 total yields according to Eq. 3.

The failure of the wounded nucleon scaling should not be a complete surprise. For increasing $\sqrt{s}$ the concept of interacting nucleons must be give way to interactions of their constituent quarks. The measured Λ yields in Figures 3 and 4 may indicate that the constituent quark concept may already be applicable in p-A collisions at the AGS. We note that the initial application of the Additive Quark Model to hadronic cross-sections was for 18 GeV/c lab momenta [14]. If we assume that the constituent quarks in the projectile are successively stripped in each collision and replaced by a quark from the sea, we can qualitatively account for the increase of the leading Λ distribution and saturation at $\nu = 3$. Furthermore, using a strange quark penalty factor of $\gamma = \frac{3}{4}N_{\Lambda}^{pp} = 0.04$, we calculate the asymptotic saturation of leading Λ production to be $3(2/3)(1-\gamma)\gamma^2 = 0.07$, approximately the observed value of Fig. 4. We can be more quantitative in predicting the yields of multi-strange baryons, where the dominant (in this model the only) contribution is expected to arise from the fragmentation of the projectile.

5. Conclusion

Λ production in p-A collisions at 17.5 GeV/c exhibits a strong deviation from the traditional wounded nucleon scaling in the number of participants. The total yields rise more quickly than the wounded nucleon model predicts, and saturate for $\nu > 3$. Comparisons of leading and non-leading Λ yields suggest that the projectile continues to fragment and produce Λs beyond the first collision.

A simple extrapolation of the observed ν scaling in p-A collisions proves to be a powerful calibration for Kaon production at the AGS and Λ production at CERN. The extrapolations are remarkable for their ability to reproduce most of the participant dependence of strange particle production for heavy-ion collisions of various center-of-mass energies.

Constituent quarks prove to be a plausible basis for understanding the main features of the ν dependence for the Λ yields. Subsequent tests of this hypothesis await further analysis and more detailed model comparisons.

6. Ackowledgements

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